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CRACKING AND EXPANSION DUE TO ALKALI-SILICA REACTION IN THE UNITED KINGDOM

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1. INTRODUCTION

In the early 1940's it was established that a number of structures in the USA had cracked as a consequence of alkali-silica reaction (ASR). Because of the USA experience, the UK Building Research Establishment decided, in 1946, to carry out a program of work to establish whether any British aggregate might be expansively reactive with the alkalis released by a Portland cement. The investigations were continued until 1958 and a series of papers published[1]. The authors concluded that UK aggregates were unlikely to be expansively reactive with high alkali cements at normal temperatures.

In part as a consequence of this work and in part because cracking due to ASR had not been encountered in the UK, ASR was not considered to be a problem. However, in the winter of 1970-71, it was noted that parts of the Val-de-la-Mare dam on the Island of Jersey had expanded and cracked. This cracking and expansion was subsequently attributed to ASR. The affected parts of the dam were cast in June to August 1960[2].

In 1976 it was concluded that ASR was the cause of extensive cracking in some 6 to 8 year old unreinforced foundation blocks at three electricity sub-stations in the South-West of England. These were the first confirmed cases of cracking due to ASR on the mainland of the UK.

2. STRUCTURES AFFECTED

To date it has been confirmed that somewhere between 100 and 300 concrete structures built between 1931 and 1975 may have cracked due to ASR. In the authors experience a high proportion of the affected structures were placed in the years 1969-71. The concrete members affected are high alkali content concretes subject to ground water, rain or heavy condensation. It is not possible to be precise regarding the number of affected structures because few have been publicized and rarely have the reasons been given as to why the judgement has been made that ASR is the cause of the visual cracking. Sometimes a judgement is made solely because the gelatinous reaction product and cracked aggregate particles have been found in the concrete. Such a judgement is not infallible as gel associated with cracked aggregate particles can be found in concretes which have not cracked as a consequence of ASR. This has meant that the reaction has sometimes been blamed for deterioration which could be attributed to other causes such as structural loading, plastic shrinkage cracking, inadequate cover, a moisture sensitive aggregate or the cracking of a finishing coat.

The structures affected include a number of electricity sub-stations, bridges, sewerage treatment works, reservoirs, a jetty, a dam, a multi-storey hospital, offices, a multi-storey car park, a race course stand and a ventilation shaft. The cracking has occurred in unreinforced and reinforced foundation bases, columns, beams and walls. Cladding panels on two buildings have also been affected. In some of the affected concrete members the cracking is visually severe and is causing major concern to the owner's of the structures. The width of the ASR cracks range up to 4.0mm or more but are generally less than 1.0mm. The depth of the ASR cracks is normally between 25 and 45mm but can be as high as 110mm. Figure 1 shows an ASR macro-crack.

Figures 2 and 3 show cracking due to ASR in an unreinforced concrete foundation block and a reinforced concrete beam. The expansion and visual cracking due to ASR is greatest in the lightly stressed and lightly reinforced parts of affected structures. This is apparent from Figures 2 and 3 where it can be seen that the magnitude of expansion is very sensitive to applied or induced compression, little expansion occurring in the direction of restraint. This observation is supported by accelerated restrained expansion tests (see Figure 4).

3. PORTLAND CEMENT

UK Portland cements have an excess of potassium oxide over sodium oxide, the ratio of potassium to sodium oxide ranging from 2:1 to 10:1 by mass. The alkali content of Portland cements currently in production in the UK range from about 0.3 to 1.0% by mass, however in 1969 to 1971 one cement was produced which had an annual average alkali content of 1.1 to 1.2% by mass. It was this cement that was used in the concrete structures in the South-West of England which cracked due to ASR.

In general the alkalis taking part in the reaction have come primarily from the Portland cement. The one known exception is a small industrial building in London where it is believed that cracking of concrete panels made with white Portland cement with an approximate alkali content of 0.3% by mass and a glass aggregate was caused by ASR. The cladding panels cracked because the glass released alkalis that increased the level of the reaction. The glass had the potential to release about 30 times as much alkali as the Portland cement.

4. AGGREGATES

The aggregate combinations which have been used in high alkali content concrete which have resulted in abnormal expansion due to ASR include.

(i) Sands dredged from the Bristol Channel or off the Isle of Wight and sand from the Wareham area of Dorset used in combination with a low porosity coarse limestone or granite. In the case of the sea dredged sand, the reactive silica is present in about 5 to 10 percent of the chert particles in the size range 1 to 8mm. There is not general agreement regarding the reactive forms of silica present within these particles; cryptocrystalline quartz and chalcedony are present but it has not been established that either of these forms of silica have reacted.

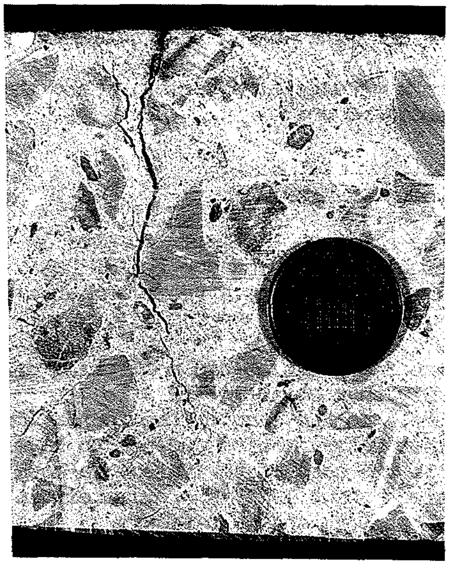

Figure 1. ASR macro-crack. Depth 65mm, width at surface 1.5mm.

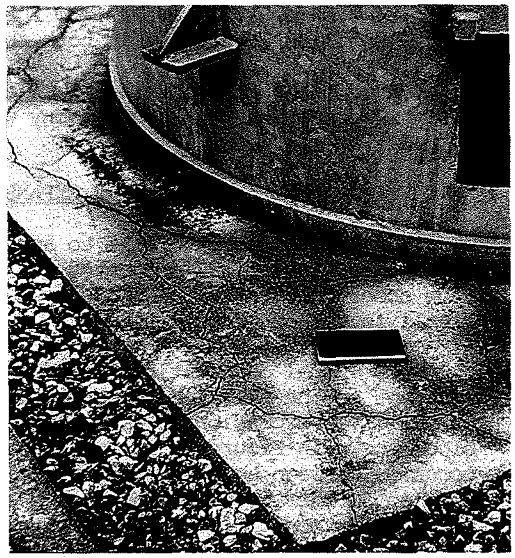

Figure 2. Cracking in a foundation block, age approximately 7 years. October 1976.

Figure 3. Cracking in a reinforced concrete beam.

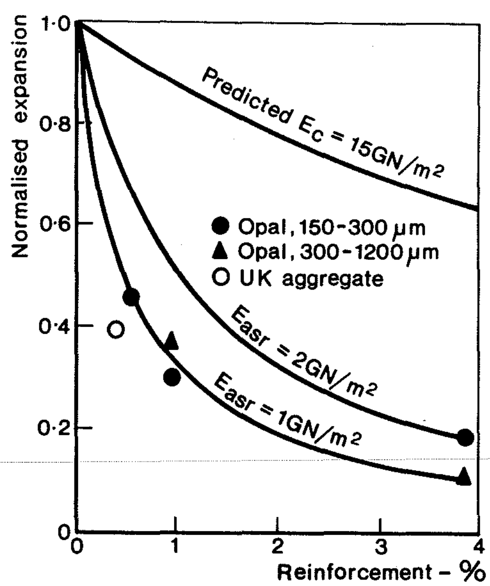

Figure 4. Relationship between normalised expansion and level of reinforcement.

(ii) Some sands and gravels from the Trent Valley in the Midlands. Here the reactive silica is present in both the coarse and fine aggregate fractions.

(iii) A combination of crushed rock and beach aggregate from Jersey. Here the reactive silica is chalcedony with associated opal.

5. TIME FOR EXPANSION TO REACH COMPLETION

The time taken for cracks to appear due to ASR is not known. However in tests on a range of UK concretes stored externally, cracking due to ASR has been observed with two aggregates at ages ranging from 3 to 4 years and at alkali levels of 6 and 7 kg/m^3.

From visual observations on several affected structures and monitoring of movement on one affected structure it is likely that at an age of 8 to 15 years the expansion is essentially complete. In the case of the foundation block shown in Figure 2, no significant further deterioration appears to have occurred between an age of 7 and 18 years. In the case of the Val-de-la-Mare dam, no further movement has been observed since about 1977, approximately 15 years after construction[2]. In the case of the beam shown in Figure 3, little further movement has occurred over the past 6 years indicating that expansion was largely complete at an age of 12 years.

The above visual observations are supported by the measurements of the movement of four, lightly prestressed concrete beams taken at an age of 18 years from the Birchfield road bridge in the Midlands[3]. These beams which were stored at the British Cement Association either in water or exposed to the weather for 7 years, have exhibited negligible further movement.

6. EFFECT ON CORE PROPERTIES

The compressive strength, tensile strength and elastic modulus of cores taken from affected members are given in Table 1. Because the cores can expand when they are extracted, the properties quoted should not be taken to be a reliable representation of the properties of the concrete in the members from which the cores were taken. All of the compressive strengths are higher than those specified.

Table 1 Strength and elastic properties of cores taken from affected members

Structural member	Age (years)	Compressive strength (MN/m^2)	Tensile strength (MN/m^2)	Elastic modulus (GN/m^2)
Beam exposed on one face.	16	55 - 65	2.9 - 4.0	20 - 30
Beam exposed on all faces.	16	39 - 54	2.8	20
Reinforced foundation.	16	40 - 50	3.3 - 4.4	11 - 25
Prestressed column.	12	78 - 104	-	-

7. REMEDIAL ACTIONS

The remedial actions which have been carried out on some of the affected structures include the following.

(i) Val-de-la-Mare dam, Jersey. In 1974 one block in this dam was post tensioned using three Macalloy high tensile steel anchor bars. Each anchor bar was post tensioned to about 8.6 ton. This action was taken because it was considered that the ASR cracking might lead to internal uplift pressures in excess of those allowed for in the design assumptions (2).

(ii) Charles Cross Car Park, Plymouth, Devon (see Figure 3). Load tests were carried out on parts of this car park in 1981, 1982, 1985 and 1986[4]. 'The results indicated that all beams behaved reasonably well under the load test' and that 'the load tests confirmed that these beams were able to carry their design load and their actual service load plus a considerable margin'. Despite the conclusions resulting from the loading tests carried out in 1981, the structure was strengthened by adding a duplicate column and edge beam system.

(iii) A reservoir in the South Midlands. This reservoir had a flat, reinforced concrete roof slab supported by nearly 500 precast, prestressed concrete columns*. About 100 of these columns had cracks up to 4mm in width running from top to bottom. These columns were replaced. Subsequent testing of cores 75 and 50mm in diameter taken from affected columns showed that the concrete was of very high quality with equivalent cube strengths ranging from 78 to 104 MN/m^2.

(iv) A race course stand. In this structure the expansive effects of the reaction were retarded by the use of ventilated cladding.

(v) On two affected structures, surface coatings were applied over small exposed areas when the structures were about 10 years of age. The surface coatings have performed reasonably well over the past 6 years, probably because the expansive effects of the reaction were largely complete when they were applied.

8. MINIMISING THE RISK OF CRACKING IN NEW CONSTRUCTION

To date there are no accepted tests for determining the expansive alkali reactivity of UK aggregates. A concrete prism expansion test is currently under study by a British Standards Working Party. The test has the major weakness that it takes up to a year to complete. As a consequence it is likely that a judgement on the reactivity of an aggregate will be based on its performance record. To date, in controlled tests, no UK cement-aggregate combination has been observed to crack due to ASR at alkali contents below 5 kg/m^3.

Recommendations for minimising the risk of cracking due to ASR in new construction have been proposed by a number of organisations and working parties [3]. To minimise the risk of cracking when it is considered that the aggregate is or may be expansively reactive with alkalis, it is recommended that one of the procedures given in sub-sections 8.1 and 8.2 be used.

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*The cement content of the affected members ranged from 450 to 650kg/m^3

8.1 Limiting the reactive alkali content of the concrete to 3 kg/m^3 or less

Here the acid soluble alkali content used is the certified average supplied by the Portland cement manufacturer or the specified average which the manufacturer has declared will not be exceeded until further notice. Because some variation in cement alkali content is inevitable in production, the actual alkali content of the concrete in an extreme case could be as high as 3.85 kg/m^3. This limit can be met by a suitable choice of Portland cement and/or cement content.

The 3 kg/m^3 limit can also be met by using a factory made cement containing fly ash or ground granulated blastfurnace slag or a site combination of ordinary Portland cement with fly ash or ground granulated blastfurnace slag. The British Cement Association, the UK Cement Manfacturers, the Building Research Establishment and the Department of Transport recommend that the active alkali contents of a fly ash or slag be taken as one sixth and one half respectively of their total alkali content. The Concrete Society recommends that their active alkali content be taken to be equal to their water soluble alkali content.

8.2 Limiting the active alkali content of the cement or binder to 0.6% or less when the alkalis from other sources do not exceed 0.2 kg/m^3 of concrete.

This limit can be met by selecting a Portland cement with a guaranteed maximum alkali content of 0.6% by mass or by using a composite cement or binder containing at least 25% by mass of fly ash or slag, one sixth and one half alkali rules being used for the fly ash and slag respectively.

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